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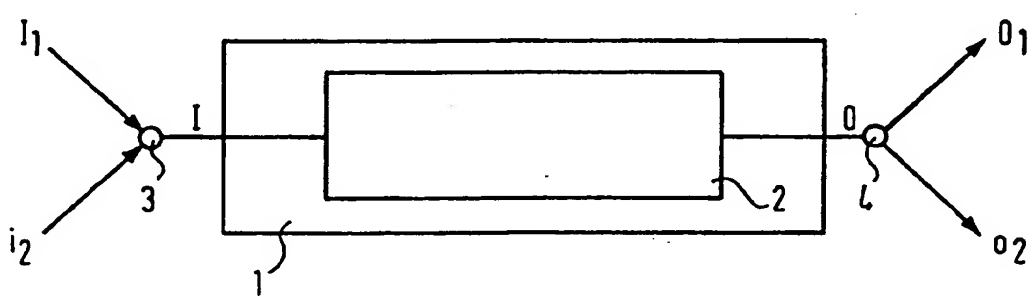
(54) Method and apparatus for determining an operating point of a non-linear amplifier of a communication channel

(57) For determining the operating point of a non-linear amplifier 2 of a communication channel 1, for example of a transponder in a communication satellite, a first input signal I_1 is transmitted through the communication channel 1 at a power level P_{I1} which drives the non-linear amplifier 2 in a non-linear operation mode. In addition, a second input signal i_2 is transmitted through the communication channel 1 simultaneously with the first input signal I_1. The second input signal i_2 is transmitted at a level below the level of the first input signal I_1. If the contribution of the second input signal i_2 to the total input of the non-linear amplifier is small, the operating point of the non-linear amplifier is determined almost only by the first input signal. Therefore, the output power P_{o2} corresponding to the second signal i_2 is determined most strongly by the input power P_{I1} of the first signal I_1. The operating point (P_I,P_O) of said non-linear amplifier (2) is determined on the basis of an output signal (o_2) of said communication channel (1) corresponding to said second signal (i_2).

Fig. 1



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Description

[0001] This invention relates to a method and an apparatus for determining an operating point of a non-linear amplifier of a communication channel, especially a transponder in a communication satellite under load.

[0002] In high frequency communication channels, a non-linear high power amplifier must often be driven at its saturation point in order to obtain the maximum possible output. For example in a satellite, but without limiting the invention to this application, a signal from an uplink station on the ground is received by an antenna, converted in frequency, filtered in an input multiplexer, and amplified by a driver limiter amplifier and a high power amplifier before being filtered in the output multiplexer and retransmitted to the ground. In order to provide a sufficient signal everywhere within the satellite footprint, the high power amplifier must be driven in its saturation point, i.e. the point of maximum in the non-linear transfer curve representing output power vs. input power, as for example shown in Fig. 6a.

[0003] The driver limiter amplifier (DLA) is a preamplifier and can be set to run in one of two modes. In linear mode, it acts as a simple linear amplifier. In limiting mode, it provides the function of an automatic level control (ALC). The DLA is normally operated in limiting mode in order to compensate short term level variations due to weather influences. In limiting mode, the DLA shall always provide the same output power to the high power amplifier (HPA), such that the HPA is permanently operated in saturation. Even if the DLA is able to maintain the HPA in saturation if the power received from the uplink ground station is below specification, it is very important that the uplink ground station power is kept on a high level since if the DLA has to compensate for uplink power, the overall signal to noise ration (SNR) is decreasing, as this is mainly driven by the SNR in the earliest stage of the signal path which is the uplink path in this case.

[0004] From the point of view of a satellite operator, it is important to know that the HPA is always operated in saturation and that the signal power from the uplink station is high enough in level at the satellite. Thus the satellite operator is forced to monitor regularly the power flux density as received at the satellite transponder input. The aim is that the video signal from the uplink station is strong enough so that under clear weather conditions, the HPA on board of the satellite is driven in saturation with the DLA in linear mode. This criterion must also be met if the HPA transfer curve has changed due to ageing.

[0005] Since the uplink power is not accurately known (for instance if the uplink is not done from a site belonging to the satellite operator itself), the operating point of the high power amplifier cannot be determined only from monitoring the downlink power. On one hand this is due to the fact that close to saturation, the input power may vary by a few dB, while the output power will only vary at most a few tenth of dB. On the other hand, if a certain amount of downlink power is measured, it cannot be determined whether the HPA is operated below or above saturation because the transfer curve is ambiguous in output power.

[0006] In order to be able to monitor the total received signal power at the HPA input, many satellites are equipped with a power monitoring system. This data can be sent together with telemetry data to the satellite operator. Apart from not all satellites being necessarily equipped with a power monitoring system, the drawback of this method is that if such a system exists in the satellite the related data consumes a certain amount of the telemetry data stream from the satellite to the operator's ground station, which could be used for other vital data. Further, the bitrate of the telemetry data stream may contain a maximum of a few kbit/s. Therefore, even if the satellite is equipped with a power monitoring system, it is also preferable to perform measurements from a ground station instead of onboard the satellite, for many reasons (i.e. failure, weight of the satellite etc.).

[0007] In addition to measuring the received power at the satellite, a satellite operator is performing regularly 'In Orbit Tests' (IOT) in order to measure the power flux density required to drive the HPA in saturation.

[0008] A first conventional method, as decribed in International Journal of Satellite Communications, Special issue on In-orbit Testing of Communications Satellites, Volume 13, Number 5, Wiley 1995 or in DE-C-33 33 418, is known as AM nulling according to which an amplitude modulated (AM) signal in the uplink is used which is swept in power until the amplitude modulation disappears completely. This point is exactly at saturation. A second conventional method of determining the transfer curve of the HPA consists of measuring transmit and receive power of a clean carrier, where all path attenuations have to be cancelled out. Both IOT measurement methods require that the transponder under test is not operated. In other words, the payload signal has to be switched off during the tests.

[0009] The necessity of switching off the payload signal during in orbit tests represents a considerable drawback not only for the user of the transponder, since communication is interrupted, but also for the operator of the satellite since the tests have to be performed in an expedited manner to keep the interruption as short as possible. In some cases it is impossible to interrupt communications via the communication channel so that the conventional methods cannot be used for testing the HPA after the satellite has entered in operation.

[0010] It is an object of the present invention to provide a method and an apparatus for determining an operating point of a non-linear amplifier of a communication channel.

[0011] It is a further object of the invention to provide such a method and such an apparatus avoiding the necessity to interrupt traffic via the communication channel.

[0012] These objects and other objects are achieved by a method for determining the operating point of a non-linear amplifier of a communication channel, wherein a first signal is transmitted simultaneously with a second signal through said communication channel and said operating point of said non-linear amplifier is determined on the basis of an output signal of said communication channel corresponding to said second signal, the input power of said first signal being such that said non-linear amplifier is operated in a non-linear mode and the input power of said second signal being below the input power of said first signal.

[0013] Preferably, the level of said second signal is approx. 20 dB or more below the level of said first signal.

[0014] In an preferred embodiment, said second signal is a pseudo noise modulated clean carrier signal and said output signal of said communication channel (1) corresponding to said second signal is a recovered carrier signal .

[0015] In another preferred embodiment, said second signal is a clean carrier signal and wherein said output signal of said communication channel corresponding to said second signal is a narrowband filtered carrier signal .

[0016] Advantageously, reference values are used together with said output signal of said communication channel corresponding to said second signal to determine the operating point of said non-linear amplifier.

[0017] These reference values can be pre-recorded for said non-linear amplifier and correspond to a transfer curve of said non-linear amplifier.

[0018] The above objects and other objects are also achieved by an apparatus for determining the operating point of a non-linear amplifier of a communication channel comprising means for transmitting a second signal through said communication channel simultaneously with a first signal being transmitted through said communication channel and means for determining said operating point of said non-linear amplifier on the basis of an output signal of said communication channel corresponding to said second signal, the input power of said first signal being such that said non-linear amplifier is operated in a non-linear mode and the input power of said second signal being below the input power of said first signal.

[0019] In a preferred embodiment, said means for determining said operating point of said non-linear amplifier on the basis of an output signal of said communication channel corresponding to said second signal comprise means for storing reference values to be used together with said output signal of said communication channel corresponding to said second signal to determine the operating point of said non-linear amplifier.

[0020] In summary, for determining the operating point of a non-linear amplifier of a communication channel, for example of a transponder in a communication satellite, a first input signal is transmitted through the communication channel at a power level which drives the non-linear amplifier in a non-linear operation mode. In addition, a second input signal is transmitted through the communication channel simultaneously with the first input signal. The second input signal is transmitted at a level below the level of the first input signal. If the contribution of the second input signal to the total input of the non-linear amplifier is small, the operating point of the non-linear amplifier is determined almost only by the first input signal. Therefore, the output power corresponding to the second signal is determined most strongly by the input power of the first signal. The operating point of said non-linear amplifier is determined on the basis of an output signal of said communication channel corresponding to said second signal.

[0021] To achieve the above objects and other objects the invention further provides a method for determining the operating point of a non-linear amplifier of a communication channel through which a payload signal is transmitted at a predetermined level, comprising: generating a first pseudo noise signal PN(t); modulating a clean carrier signal f(t) with said first pseudo noise signal PN(t) to generate a PN modulated clean carrier signal s(t); transmitting said PN modulated clean carrier signal s(t) simultaneously with said payload signal through said communication channel at a level below the level of said payload signal; receiving a receive signal s'(t) corresponding to said PN modulated clean carrier signal s(t) after having traveled through said communication channel; correlating said receive signal s'(t) with said first pseudo noise signal PN(t) to generate a recovered carrier signal f'(t); and determining the operating point of said non-linear amplifier of the communication channel on the basis of said clean carrier signal f(t) and said recovered carrier signal f'(t).

[0022] Advantageously, the level of said PN modulated clean carrier signal s(t) is approx. 20 dB or even approx. 30 dB or more below the level of said payload signal.

[0023] According to the invention, said first pseudo noise signal PN(t) is a binary pseudo noise sequence, said binary pseudo noise sequence being generated by means of a feed back shift register or a memory device in which a sequence of values of a pseudo noise signal is stored.

[0024] Said correlating of said receive signal s'(t) and said first pseudo noise signal PN(t) can be achieved by delaying said first pseudo noise signal PN(t) and multiplying the delayed first pseudo noise signal PN(t) and said receive signal s'(t).

[0025] In a preferred embodiment, a gain is determined on the basis of said clean carrier signal f(t) and said recovered carrier signal f'(t) and said gain is used to determine the input power of said payload signal. Reference values are used to derive from said gain the input power of said payload signal, said reference values having being pre-recorded for said non-linear ampli-

fier and representing a gain curve or transfer curve of said non-linear amplifier over the input power of said payload signal.

[0026] The method according to the invention is advantageously applicable if said communication channel is a transponder of a communication satellite.

[0027] To achieve the above objects and other objects the invention furthermore provides an apparatus for determining the operating point of a non-linear amplifier of a communication channel through which a payload signal is transmitted at a predetermined level, comprising first pseudo noise signal generating means for generating a pseudo noise signal PN(t); first modulating means for modulating a clean carrier signal f(t) with said first pseudo noise signal PN(t) to generate a PN modulated clean carrier signal s(t); transmitting means for transmitting said PN modulated clean carrier signal s(t) simultaneously with said payload signal through said communication channel at a level below the level of said payload signal; receiving means for receiving a receive signal s'(t) corresponding to said PN modulated clean carrier signal s(t) after having traveled through said communication channel; and first correlating means for correlating said receive signal s'(t) with said pseudo noise signal PN(t) to generate a recovered carrier signal f'(t).

[0028] Advantageously, the level of said PN modulated clean carrier signal s(t) is at least 20 dB or even at least 30 dB below the level of said payload signal.

[0029] According to the invention, said first pseudo noise signal generating means (9) is a feed back shift register or a memory device in which a sequence of values of a pseudo noise signal is stored.

[0030] In summary, for determining the operating point of a non-linear amplifier of a communication channel, for example of a transponder in a communication satellite, a clean carrier signal f(t) is modulated with a pseudo noise signal PN(t) and transmitted through the communication channel at a level below the level of a payload signal which is transmitted via the communication channel simultaneously. The received signal s'(t) is correlated with the same pseudo noise signal PN(t) to obtain a recovered carrier signal f'(t). The power of the clean carrier signal f(t) and of the recovered carrier signal f'(t) are used to determine the gain of the signal and on the basis of reference values (calibration curves) the input power of the payload signal. Since the PN modulated clean carrier signal s(t) is transmitted at a low level, it is possible to perform measurements without switching off the payload signal, the input power of which defining the operating point of the non-linear amplifier.

[0031] An important advantage of the method and the apparatus according to the invention is of course that the payload signal does not have to be switched off for performing the measurements. This limits considerably the downtime required for maintenance and verification of the communication channel, and thus increases availability of services.

[0032] In the following an embodiment of the invention will be described in greater detail and with reference to the drawings.

Fig. 1	shows a schematic diagram of a communication channel comprising a non-linear amplifier;
Fig. 2	shows transfer curves of a non-linear amplifier;
Fig. 3	shows a diagram of gain difference over input power of a non-linear amplifier;
Fig. 4	shows a schematic diagram of a transponder of a communication satellite;
Fig. 5	shows a schematic diagram of an embodiment of an apparatus according to the invention; and
Fig. 6a and 6b	show transfer curves and gain curves of a non-linear amplifier for large and small signals.

[0033] To describe the invention in a more general application, Fig. 1 shows a communication channel 1 comprising a non-linear amplifier 2 for amplifying the signals transmitted through the communication channel. If a total input signal I is fed to an input 3 of the communication channel 1, the signal travels through the communication channel 1, is amplified by the non-linear amplifier 2, and is output as an total output signal O at an output 4 of the communication channel 1.

[0034] As can be seen in Fig. 2, which shows a transfer curve A of a travelling wave tube amplifier (TWTA), as an example of a non-linear amplifier, a non-linear mode of operation is effected if the input power P_I of the total input signal I is high enough to operate the non-linear amplifier in the non-linear region (a) of its transfer curve. In some applications the goal is to drive the non-linear amplifier 2 in its saturation point as indicated by S in Fig. 2 to obtain maximum output power. As in the linear region (b) of the transfer curve, each operating point of the non-linear amplifier in the non-linear region (a) is defined by a specific input power P_I of an input signal I and a corresponding output power P_O of an output signal O of the communication channel. In saturation the input signal provides an input power of P_{IS} corresponding to an output power of P_{OS}.

[0035] According to the invention, a first input signal I_1 is transmitted through the communication channel 1 at a power level P_{I1} which drives the non-linear amplifier 2 in a non-linear operation mode. In addition, a second input signal i_2 is transmitted through the communication channel 1 simultaneously with the first input signal I_1.

The second input signal i_2 is transmitted at a level below the level of the first input signal I_1. In other words, the input power P_{I2} of the second signal i_2 is lower than the input power P_{I1} of the first signal I_1. If the contribution of the second input signal i_2 to the total input of the non-linear amplifier is small, the operating point of the non-linear amplifier is determined almost only by the first input signal. Therefore, the output power P_{o2} corresponding to the second signal i_2 is determined most strongly by the input power P_{I1} of the first signal I_1. Thus, any variation in input power of the first signal causes a variation in output power of the second signal. To achieve this effect the second input signal should be some 15 to 30 dB or more, depending on the application, below the first input signal. This is indicated in the linear region (b) in Fig. 2 which shows a transfer curve B representing the output power of a small input signal plotted against the input power of a large input signal.

[0036] As also indicated in Fig. 2, in the non-linear region (a) the transfer curve B of the second input signal falls off much faster than the transfer curve of the first input signal so that any variation of the output power of the second input signal caused by a variation of the input power of the first input signal can be measured much easier as long as the part o_2 of the output signal O corresponding to the second input signal i_2 can be separated from the part O_1 of the output signal O corresponding to the first input signal I_1, as indicated in Fig. 1.

[0037] The separation of the contributions O_1 and o_2 of the first and second input signals I_1 and i_2, respectively, in the output signal O may be achieved in several different ways. For example, if the first input signal I_1 is a FM or QPSK signal, the second input signal i_2 may be a pseudo noise modulated clean carrier signal as will be explained further below in greater detail. By correlating the output signal with the pseudo noise signal used for generating the second input signal i2 the carrier signal can be recovered. The recovered carrier signal represents the output signal o_2 corresponding to the second input signal i_2. As an alternative, the second input signal could be a clean carrier signal having a frequency which avoids deterioration of the second input signal by the first input signal, for example having a frequency outside the frequency band of the first input signal. By narrowband filtering the output signal O at the frequency of the second input signal the part o_2 of the second input signal i_2 in the total output signal O can be determined.

[0038] According to the invention, the operating point of the non-linear amplifier can be determined in different ways. If the input power of the first and second input signal is known the output power corresponding to these signals can be measured and a transfer curve or a gain curve, an example being shown in Fig. 6b, can be obtained. If the transfer curve or the gain curve is known, the input power of the first input signal driving the non-linear amplifier in a non-linear mode of operation can be determined by transmitting a second input signal of a known input power through the communication channel and measuring the output power corresponding to the second input signal.

[0039] It should be noted that in the non-linear mode it is difficult if not impossible to determine the input power of the first signal from the output power of the first input signal, especially if the non-linear amplifier is to be operated in saturation, since even relatively large variations in input power result in only slight variations in output power of the first signal, respectively. Further, an ambiguity exists in the non-linear region around the saturation point S as can be seen in Fig. 2 so that the input power cannot unambiguously be determined if a certain level of output power is measured as two levels of input power correspond thereto.

[0040] However, according to the invention, the input power of the first signal and, therefore, the operating point of the non-linear amplifier can be determined on the basis of the input power of the second input signal and the transfer curve or the gain curve (or any other representation of the above described relation between the large and the small input signal), if the second input signal is a small signal compared to the first input signal, as explained above. For example, as shown in Fig. 2, if the output power of the second signal is measured to be P_{O2a} the transfer curve B of the second signal i_2 allows to determine the input power of the first signal I_1 to be P_{I1a} without measuring the output power of the first signal at all.

[0041] Over a long period the transfer curve and the gain curve of the non-linear amplifier may change due to ageing. According to the invention, such a change of the transfer curve can be detected by determining the operating point of the non-linear amplifier on the basis of first and second input signals I_1 and i_2 the individual input powers P_{I1} and P_{I2} of which are known. By measuring the individual output powers P_{O1} and P_{O2} corresponding to the first and second input signal I1 and i2 the operating point can be determined and compared to the operating point derived on the basis of the transfer curve (or any other representation thereof).

[0042] To explain this aspect of the invention in some further detail, Fig. 3 shows a diagram representing a gain difference between the first signal and the second signal, i.e. $gains_{small}$ - $gain_{large}$, plotted over the input power of the first signal. If an operating point (P_{Ia}, P_{Oa}) is determined as described above which is not on the pre-recorded curve C, ageing of the non-linear amplifier has cause a shift of the curve, indicated by curve C'. Although not shown in Fig. 2, a similar shift can also be seen in the transfer curve of the non-linear amplifier.

[0043] For the purpose of describing a more specific embodiment of the invention, but without limiting the invention to this application, Fig. 4 shows the components of a transponder in a communication satellite as an example for a communication channel.

[0044] A transponder of a communication satellite comprises a receiving antenna 11 for receiving an

uplink signal (= the first input signal) send from a uplink ground station (not shown). An output signal of said receiving antenna 11 is fed to an input demultiplexer (IMUX) 13 after frequency conversion in frequency converter 12. Said input demultiplexer 13 comprises several first filters 14-1 to 14-n for separating individual signals within the signal from the antenna. Typically, one filter is provided for each signal to be separated from the other signals received via said receiving antenna 1 and corresponds to a communication channel. The n output signals of said input demultiplexer 13 are fed to a corresponding number of driver limiter amplifiers 15a-1 to 15a-n and high power amplifiers 15b-1 to 15b-n. In each of the high power amplifiers a travelling wave tube (TWT) is employed for amplifying the output signals of said input demultiplexer 13. The high power amplifiers 15b-1 to 15b-n are non-linear amplifiers having a transfer curve and gain curve as indicated by curves A in Fig. 6a and 6b, respectively. If not set to a linear mode the driver limiter amplifiers 15a-1 to 15a-n are either limiting or amplifiying the input signal received from the input demultiplexer 13 before being fed to the respective high power amplifier. The amplifier output signals are passed through second filters 16-1 to 16-n which are part of an output multiplexer (OMUX) 17 combining the n amplifier output signals. The output signal of said output multiplexer 17 is fed to a transmitting antenna 18 for being transmitted to the desired area on the ground.

[0045] The operating point of each of said high power amplifiers 15b-1 to 15b-n depends on the payload signal (the first input signal) from the uplink ground station, which signal should be such that the amplifier is driven in saturation in order to achieve maximum output power. Within predetermined limitations, the driver limiter amplifiers 15a-1 to 15a-n can be set such that each of said high power amplifiers is operated in its saturation point. For the measurement described below the driver limiter amplifiers are set to linear operation.

[0046] According to the invention, in a ground station (10) as shown in Fig. 5, a pseudo noise signal PN(t) is generated by means of a pseudo noise signal generator 19, for example a feed back shift register or a memory device in which a sequence of values of a pseudo noise signal is stored. The pseudo noise signal PN(t) has a very sharp autocorrelation function at zero delay. This allows to determine the time delay between the locally generated pseudo noise signal PN(t) and a received signal which is delayed due to the propagation time. A clean carrier signal f(t) is modulated with said pseudo noise signal PN(t) by means of a first multiplier 20 to form a PN modulated clean carrier signal $s(t) = PN(t) \times f(t)$. The PN modulated clean carrier signal s(t) is fed to an upconverter 21 and via a high power amplifier 22 to an antenna 23 which transmits the PN modulated clean carrier signal s(t) (= the second input signal) to the transponder of the communication satellite under test. However, from the viewpoint of a user transmitting a payload signal to the satellite, the transponder remains usable during the test and can be continuously supplied with a payload signal.

[0047] According to the invention, the level of the transmitted PN modulated clean carrier signal s(t) is sufficiently below the level of the payload signal, for example about 20 to 30 dB or more, such that the payload signal is not notably deteriorated. For this reason, the PN modulated clean carrier signal s(t) can be transmitted while the communication channel is in use, i.e. simultaneously with a payload signal being transmitted to the transponder of the satellite from the same or from another ground station.

[0048] In the embodiment, antenna 23 is also used to receive the signal re-transmitted by the transponder of the satellite, in other words the signal which has traveled through the communication channel. The output signal of antenna 23 is passed through a downconverter 24 to obtain a receive signal s'(t) which is fed to a second multiplier 25 receiving also the same but delayed pseudo noise signal PN(t). The delay is generated by delaying means 26 which are set such that the output of the second multiplier 25 becomes maximum. Thereby, the receive signal s'(t) is multiplied, in other words correlated with the very same pseudo noise signal PN(t) which has been used for generating the PN modulated clean carrier signal s(t) and a recovered carrier signal f'(t) is obtained which is only delayed and attenuated in comparison with the clean carrier signal f(t). The path attenuation is constant as free space loss does practically not vary with the distance between the satellite and the ground station. Since atmosperical attenuation can be measured with radiometers, it can be taken into account as well as the gain of the ground station antenna at the corresponding frequencies. Thus, the input power of the clean carrier signal f(t) and the output power of the recovered carrier signal f'(t) can be measured to determine the gain of this signal. The input power of the payload signal is determined on the basis of said gain and of reference values or calibration curves, which are shown in Fig. 6a and 6b and which will be explained in greater detail further below.

[0049] If for example as shown in Fig. 6b the gain of the small signal is measured to be -4 dB the input power of the large signal is -1 dB. Here it should be noted how powerful this measurement is compared to measuring the output power: while the output power of the large signal changes by less than 0.05 dB for the input power varying from 0 dBW to -1 dB, the gain of the small signal varies by almost 2 dB.

[0050] In Fig. 6a, transfer curves for a large signal (A) and three small signals (B_1, B_2, B_3) over a travelling wave tube amplifier (TWTA) are shown. For simplicity, the values are given relative to the saturation point of the amplifier. This means that in Fig. 6a 0 dB input power corresponds to 0 dB output power. The three small signals (B_1, B_2, B_3) are 20 dB, 30 dB, and 40 dB below the large signal, respectively. In Fig. 6b, gain curves for the large signal (A) and the three small sig-

nals (B_1, B_2, B_3) are shown. Again, the values are given relative to the saturation point of the amplifier so that in Fig. 6b 0 dB input power corresponds to 0 dB gain. As the gain of the small signals does not depend on the input power difference relative to the large signal but only on the input power of the large signal, the gain curves for the three small signals overlap completely. The above described transfer curves and gain curves, shown in Fig. 6a and 6b, are obtained as calibration curves for each amplifier in the satellite in order to determine the operating point of the individual amplifier later on. Advantageously, the calibration curves are recorded in the form of reference values which are stored in appropriate storage means for being used in determining the operating point of the non-linear amplifier.

[0051] For measuring the calibration curves, a large signal and a small signal are generated where the small signal is for example 20 dB, 30 dB, or 40 dB below the large signal. The large and the small signal may be a clean carrier or the large signal may be a FM or OPSK modulated signal to come as close as possible to real operation conditions and the small signal may be a pseudo noise modulated clean carrier signal. Both signals, i.e. the large and the small signal, are combined and transmitted to the transponder. The total input signal received by antenna 11 is fed to the input of the high power amplifier (TWTA). The combined signal is swept in power, thus the level difference between the large signal and the small signal at the input will always remain the same. However, as an alternative, the power of the small signal may be kept constant as it does not substantially influence the operating point of the non-linear amplifier. The output signal of the high power amplifier (TWTA) is fed to antenna 18 via output demultiplexer 17 and the output levels corresponding to both input signals are measured separately.

[0052] In the calibrating curve as shown in Fig. 6a, the output power of the large signal (which is almost equal to the total output power as the small signal has a negligible contribution) is given as a function of the input power of the large signal. The output power of the small signal is also given as a function of the input power of the large signal. In Fig. 6b, the gain of the large signal and the gain of the small signals are given as a function of the input power of the large signal.

[0053] In the ground station shown in Fig. 5, means 27 for determining a gain on the basis of said clean carrier signal f(t) and said recovered carrier signal f'(t) are provided, receiving both the clean carrier signal f(t) and the recovered carrier signal f'(t). Furthermore, means 28 for deriving the input power of said payload signal from reference values and from said gain. The output of said means 27 for determining a gain are supplied to said means 28 for deriving the input power of said payload signal. The reference values are stored in and supplied from means 29 for storing said reference values. The said reference values have been pre-recorded for said non-linear amplifier and represent a gain curve or transfer curve of said non-linear amplifier over the input power of said payload signal, as described with respect to Fig. 6a and 6b.

[0054] Only pseudo noise signals have been discussed above because these signals can be generated comparatively easily. However, true noise signals can be used in the method and the apparatus according to the invention. Properties of true and pseudo noise signals are well known to those skilled in the art and are described, for example in Bernard Sklar, "Digital Communications - Fundamentals and Applications", Prentice Hall, 1988.

Claims

1. Method for determining an operating point of a non-linear amplifier (2) of a communication channel (1) wherein a first signal (I_1) is transmitted simultaneously with a second signal (i_2) through said communication channel (1) and said operating point (P_I,P_O) of said non-linear amplifier (2) is determined on the basis of an output signal (o_2) of said communication channel (1) corresponding to said second signal (i_2), the input power (P_{I1}) of said first signal (I_1) being such that said non-linear amplifier (2) is operated in a non-linear mode and the input power (P_{O2}) of said second signal (i_2) being below the input power (P_{O1}) of said first signal (I_1).

2. Method according to claim 1, wherein the level of said second signal (i_2) is approx. 20 dB or more below the level of said first signal (I_1).

3. Method according to any one of claims 1 or 2, wherein said second signal (i_2) is a pseudo noise modulated clean carrier signal ($s(t) = PN(t) \times f(t)$) and wherein said output signal (o_2) of said communication channel (1) corresponding to said second signal (i_2) is a recovered carrier signal (f'(t)).

4. Method according to any one of claims 1 or 2, wherein said second signal (i_2) is a clean carrier signal (f(t)) and wherein said output signal (o_2) of said communication channel (1) corresponding to said second signal (i_2) is a narrowband filtered carrier signal (f'(t)).

5. Method according to any one of claims 1 to 4, wherein reference values are used together with said output signal (o_2) of said communication channel (1) corresponding to said second signal (i_2) to determine the operating point of said non-linear amplifier.

6. Method according to claim 5, wherein said reference values have been pre-recorded for said non-linear amplifier and correspond to a transfer curve of said non-linear amplifier.

ciated with frequency demodulators is used in cooperation with phase-locked loops in a new demodulator to provide improved démodulation of all of several FM carriers including weaker signals in the presence of dominant carriers. A frequency demodulator converts the instantaneous frequency of the applied signal to a voltage. When the sum of two or more signals is present at the input to the demodulator of the present invention, the output voltage $m_o(t)$, is proportional to the instantaneous frequency of the dominant portion of the input signal. Thus, the dominant signal is said to capture the demodulator.

When $m_o(t)$ is used to frequency modulate another sinusoid, then a replica of the original dominant signal is created in the receiver. The replica signal is now isolated from the other weaker receiver input signals and can be subtracted from the composite input to effectively suppress the dominant signal. After subtraction, weaker carriers of the input signal remain. The remaining signal then can be successively demodulated in the same way virtually as many times as desired for demodulation of as many component carriers of the input signal as desired.

For effective cancellation using the present invention, the carrier frequency and the extent of modulation of the replica signal must be substantially the same as the dominant signal. In practice, it is not possible to achieve this condition using a conventional signal source and frequency modulator. However, by using a voltage-controlled oscillator (VCO) in a PLL, near exact replication of the dominant signal is possible. Thus, when the phase-locked loop is operated as a frequency demodulator, the output of the VCO is the replica of the dominant input signal to be cancelled.

Recovery of weaker signal information is inherent in the design of a signal receiving system constructed according to the principles of the present invention. A plurality of output signals representing the messages contained in the modulation of a succession of dominant input signals, derived from remaining components of the original input signal in descending order of dominance, is obtainable from each phase-locked loop demodulator comprising the signal receiving system of the present invention. Consequently, this invention makes possible multiple reuse of FM bands, that is, several FM carriers having unrelated messages can coexist in the same frequency band with all or selected messages being recoverable by application of this invention.

The present invention permits and includes the concept of power division multiplexing whereby a number of messages (customers) share transmitter power with each other using the same frequency band simultaneously. This concept is consistent with other well understood and implemented techniques such as time division multiplexing and frequency division multiplexing.

Description of the Drawing

Figure 1 is a block diagram of a signal receiving system constructed according to the principles of the present invention.

Figure 2 is a block diagram of the variable delay employed in the system of Figure 1.

Figure 3 is a block diagram of the variable-gain difference amplifier employed in the system of Figure 1.

Figure 4 is a block diagram of the PLL employed in the system of Figure 1.

Description of the Preferred Embodiment

Referring to Figure 1, signal receiving system 10 comprises a plurality of PLL demodulators, each of which includes a mixer, lowpass filter (LPF) and VCO. The system further includes pluralities of variable delays and variable-gain difference amplifiers coupled, respectively, to each of the phase-locked loop demodulators as shown and further described elsewhere in this specification.

With the continuing reference to Figure 1, input signal $V_i(t)$ is assumed to include many FM carrier signals of various strengths and will be described in more detail elsewhere in this specification. The receiving system of the present invention may be connected to the front end, i.e. radio frequency (RF) antenna, RF amplifier, mixer and intermediate frequency (IF) amplifier, of any conventional superheterodyne radio receiver. In such systems, the mixer down converts received RF energy into a received IF signal. Typically, the received IF signal preserves the signal-to interference ratio of the received RF energy, and the frequencies of the desired as well as interfering signals. Thus, frequency components of the RF energy are preserved in the IF signals.

Phase-locked loop 11 (also referred to as PLL_i) comprises mixer 102, LPF 103 and VCO 104. One input of mixer 102 is coupled to the input signal $V_i(t)$. The output of mixer 102 is coupled to the input of LPF 103. The output of LPF 103 is coupled to the input of VCO 104 and produces message information $m_i(t)$ demodulated from the most dominant FM signal. The output of VCO 104 is applied to another input of mixer 102 and to the input of difference amplifier 106.

PLL_2, PLL_3 . . . PLL_n are essentially the same circuits as that just described for PLL_i.

The input signal is also applied to the input of variable delay 105. The outputs of delay 105 and VCO 104 are applied to the inputs of variable-gain difference amplifier 106. The output of amplifier 106 comprises input signal $V_i(t)$ with the most dominant carrier suppressed. Demodulation of the most dominant carrier of the output signal from amplifier 106 is provided by PLL_2. It should be noted that the most dominant carrier of the output signal from amplifier 106 is, typically, the second most dominant carrier of input signal $V_i(t)$.

Since PLL_3 is substantially the same as PLL_1 and PLL_2, demodulation of the third most dominant carrier of input signal $V_i(t)$ is provided by PLL_3. The input of PLL_3 is coupled to the output of variable-gain amplifier 116. One input of variable gain amplifier 116 is coupled to the output of the VCO forming a part of PLL_2 (shown). The other input of difference amplifier 116 is coupled to the output of variable-gain amplifier 106 via delay 115. Again, the output signal from variable-gain amplifier 116 is the input signal $V_i(t)$ with the first two most dominant carriers suppressed.

To the extent that the strength of the individual carriers of input signal $V_i(t)$ permit, any number of individual demodulations of the carriers of $V_i(t)$ can be obtained as each such carrier becomes dominant in later stages of the receiving system of the present invention. Thus, recovery of the information contained in the modulation of all carriers of $V_i(t)$, in descending order of dominance, is obtained.

Variable delay 105 may also be merely a variable-phase shift circuit for appropriately adjusting the phase of the output from the previous stage of receiving system 10 for coherence with the output of VCO 104. Delay 105 may use operational amplifier circuit techniques in order to alter the signal phase in a precise and predictable manner. Thus, variable delay 105 may include four (4) LM-318 operational amplifier stages, where each stage has the possibility of continuously variable phase change from 0 to 90°, as shown in Figure 2. Alternatively variable delay 105 may comprise circuits or systems creating delay directly (e.g., switched capacitor filters).

Variable-gain difference amplifier 107 may be any circuit suitable for combining a signal having the same amplitude and frequency as one component of another signal. Such circuits are well known and may include an LM-318 operational amplifier con figured as shown in Figure 3.

Phase-locked loops, PLL_1 . . . PLL_n, are conventional, each consisting of such well known components as a mixer, a lowpass filter and a reference voltage-controlled oscillator for producing a reference or replica signal. Typically, all of the components of a PLL are integrated as a single semiconductor product, such as part number 562, manufactured by Signetics, Inc., which may be used in the present invention as shown in Figure 4.

When the VCO follows the frequency change of $V_i(t)$, the VCO output is the frequency of the dominant component of $V_i(t)$ because of capture effect.

Input signal $V_i(t)$ is given by the following relation:

$$
\begin{aligned}
V_i(t) = {} & B_1\cos[\omega_1 t + {}_0\!\int^t m_1(a)da] \\
& + B_2\cos[(\omega_1 + \epsilon_2)t + {}_0\!\int^t m_2(a)da] \\
& \;\vdots \\
& + B_n\cos[(\omega_1 + \epsilon_n)t + {}_0\!\int^t m_n(a)da]
\end{aligned}
$$

If $s_1(t) = B_1\cos[\omega_1 t + {}_0\!\int^t m(a)da]$, the most dominant signal component of $V_i(t)$,

and

$$
\begin{aligned}
j_2(t) = {} & B_2\cos[(\omega_1 + \epsilon_2)t + {}_0\!\int^t m_2(a)da] \\
& + B_3\cos[(\omega_1 + \epsilon_3)t + {}_0\!\int^t m_3(a)da] \\
& \;\vdots \\
& + B_n\cos[(\omega_1 + \epsilon_n)t + {}_0\!\int^t m_n(a)da],
\end{aligned}
$$

remaining successively dominant signal components of $V_i(t)$,

$= s_2(t) + s_3(t) + \cdots + s_n(t)$

then, $V_i(t) = s_1(t) + j_2(t)$.

Modulation components, m_1 . . . m_n, are arbitrary. Carrier frequencies, f_1, f_2 . . . f_n where f_k = are typically in the same band. If all other components of $V_i(t)$, namely $j_2(t)$, individually do not exceed in amplitude the carrier signal $s_1(t)$, then the output $x_1(t)$ of PLL_1 is equal to $m_1(t)$ because of the capture effect of the first demodulator. Since message $m_1(t)$ is recovered from the dominant carrier of $V_i(t)$, and since VCO 104 is a frequency modulator itself being modulated by $m_1(t)$, then $y_1(t)$ of Figure 1 is a replica of the dominant carrier of $V_i(t)$.

Referring again to Figure 1, the delays and variable-gain 20 summers are adjusted to minimize the level of previously dominant signals present at the input of the PLL of interest. Owing to the capture effect of subsequent FM demodulator stages, complete suppression of the undesired signal components is unnecessary; i.e., it is not necessary that $z_k(t)$ equals $j_k(t)$ where $z_k(t)$ is a signal in which $s_{k+1}{}^{(t)}$ is the dominant component. Rather, it is only necessary that the level of $S_{k-1}{}^{(t)}$ merely exceed the level of all other signal components of $j_k(t)$ where k is any integer in the range 1, 2, . . . n, in order to recover information from any component of $V_i(t)$.

The present invention also incorporates power division multiplexing whereby a number of messages (customers) share transmitter power with each other using the same frequency band simultaneously. This concept is consistent with other well understood and implemented techniques such as

time division multiplexing and frequency division multiplexing.

With reference to Figure 1, the average power of $V_i(t)$ is distributed among its components $s_1(t)$, $s_2(t)$, --- $s_N(t)$. The greater share of this total average power arises from $s_1(t)$ because it is the dominant signal. Likewise, the average power of $s_j(t)$ exceeds that of $s_{j+1}(t)$ where $j = 0,1,2,3,$ --, N. In this manner, the total average power is allocated to the various components of $V_i(t)$ or multiplexed among the various messages in that assigned FM band all of which is being used by each customer. Since a power lever is assigned to each user, the result is power division multiplexing in the same sense that frequency band assignment to each user is frequency division multiplexing and time slot assignment to each user is time division multiplexing.

While the present invention has been particularly shown and described with respect to a preferred embodiment thereof, it should be understood by those skilled in the art that changes in form and detail may be made without departing from the spirit of the invention or exceeding the scope of the appended claims. In particular, for example, this invention may be used for phase modulated carriers as well as for FM carriers.

Claims

1. Signal receiving system for receiving an input signal having a plurality of modulated carrier signals included therein, said system characterized by:
first demodulator means (PLL_1) for receiving the input signal, for producing a signal representing the demodulated message of the most dominant carrier signal of said input signal, and for producing a replica signal of said dominant carrier signal;
delay means (105) coupled to the demodulator means (PLL_1) for receiving the input signal, and for producing a first signal identical to said input signal except that said first signal is selectively delayed with respect to said input signal;
output means (106), coupled to the delay means (105) and to the demodulator means (PLL_1), for receiving and combining said first signal produced by said delay means (106) and said replica signal produced by said demodulator means (PLL_1), and for producing an output signal representing the input signal with the most dominant carrier suppressed; and
second demodulator means (PLL_2) coupled to said output means (106) for receiving the output signal produced thereby, for producing a signal representing the demodulated message of the second most dominant carrier of said input signal, and for producing a replica signal of said second most dominant carrier signal.

2. A signal receiving system as in Claim 1 characterized by:
a plurality of demodulator means (PLL_1, PLL_2, PLL_3, ..., PLL_N) each for producing a signal representing the demodulated message of the next successively dominant carrier signal in said input signals, and for producing a replica signal of said next successively dominant carrier signals;
a plurality of output means (105, 115, 15); and
a plurality of delay means (105, 115, 15) having an input each respectively coupled to the output of one of said output means (106, 116, 16) for producing first signals identical to signals received therefrom selectively delayed with respect to said received signals;
each of said plurality of output means (106, 116, 16) being coupled to one of said demodulator means (PLL_1, PLL_2, PLL_3, ..., PLL_N) and one of said delay means (106, 116, 16) for receiving and combining said first and said replica signals produced thereby, and for producing a plurality of output signals, each of said output signals having the next successively dominant carrier signal of said input signal suppressed.

3. A method for receiving an input signal having a plurality of modulated carrier signals included therein, said method characterized by the steps of:
producing a signal representing the demodulated message of the most dominant carrier signal of said input signal;
producing a replica signal of the most dominant carrier signal;
producing a first signal identical to said input signal except that said first signal is selectively delayed with respect to said input signal;
combining said replica and said first signals to produce an output signal representing the input signal with the most dominant carrier suppressed; and
producing a signal representing the demodulated message of the second most dominant carrier signal of said input signal.

4. The method as in Claim 3 characterized by the additional steps of:
producing a plurality of signals representing the demodulated message of the next successively dominant carrier signal in said input signal;
producing a plurality of replica signals of the next successively dominant carrier signals;
producing a plurality of first signals identical to said input signal with the immediately preceding dominant signals suppressed, said first signals being selectively delayed with respect thereto; and
combining said pluralities of replica and first signals to produce a plurality of output signals, each of said output signals having the next successively

dominant carrier signal of said input signal suppressed.

5. A signal receiving system for receiving an input signal having a plurality of modulated carrier signals included therein, said system characterized by:
first phase lock loop means (PLL_1) for receiving said input signal, said first phase lock loop means (PLL_1) for generating a first signal representing the demodulated message of the most dominant carrier signal of said input signal and for generating a first replica signal of said most dominant carrier signal;
delay means (105) coupled to said first phase lock loop means (PLL_1) for receiving said input signal, said delay means (105) for producing a delayed signal identical to said input signal, said delayed signal being selectively delayed with respect to said input signal;
output means (106) coupled to said delay means (105) and to said first phase lock loop means (PLL_1) for receiving and combining said delayed signal produced by said delay means (105) and said first replica signal generated by said first phase lock loop means (PLL_1), said output means (106) for producing an output signal representing said input signal having said most dominant carrier signal suppressed; and
second phase lock loop means (PLL_2) coupled to said output means for receiving said output signal produced thereby and for generating a second signal representing the demodulated message of the second most dominant carrier signal of said input signal and for producing a second replica signal of said second most dominant carrier signal.

6. The signal receiving system as in Claim 5 characterized in that said first phase lock loop means (PLL_1) comprises:
mixer means (102) having first and second input ports, said input signal coupled to said first input port and said first replica signal coupled to said second input port, said mixer means (102) combining said input signal and said replica signal for producing signals representing the sum and the difference of said input and first replica signals;
lowpass filter means (103) coupled to said mixer means (102) for receiving and filtering said signals produced by said mixer means (102) and for producing said first signal representing said demodulated message of said most dominant carrier signal; and
oscillator means (104) coupled to said lowpass filter means (103) for generating a signal having a frequency substantially equal to the frequency of said most dominant carrier signal, said oscillator means (104) responsive to said first signal for modulating said signal for producing said first replica signal of said most dominant carrier signal.

7. The signal receiving system as in Claim 6 characterized in that said oscillator means (104) comprises a voltage controlled oscillator.

8. The signal receiving system as in one of the preceding Claims characterized in that said second phase lock loop means (PLL_2) comprises substantially identical components as said first phase lock loop means (PLL_1), said second phase lock loop means (PLL_2) being tuned to lock at the frequency of said second most dominant carrier signal.

9. The signal receiving means as in one of the preceding Claims characterized in that said delay means (105) comprises a plurality of amplifier stages, each said amplifier stage providing selectable continuously variable phase change over a predetermined range.

10. The signal receiving means as in as in one of the preceding Claims characterized in that said output means (106) comprises a variable gain differential amplifier having a first input port coupled to said delay means (105) for receiving said delayed signal and a second input port coupled to said first phase lock loop means (PLL_1) for receiving said first replica signal, said differential amplifier combining said delayed signal and said first replica signal for producing said output signal, said output signal representing said input signal with said most dominant carrier signal suppressed.

11. A signal receiving system as in Claim 5 characterized by:
a plurality of successive phase lock loop means (PLL_1, PLL_2, PLL_3, ..., PLL_N) each of said successive phase lock loop means tuned to the frequency of the next successive dominant carrier signal of said input signal, each of said successive phase lock loop means for generating a signal representing the demodulated message of the next successive most dominant carrier signal in said input signal and generating a replica signal of said next successive most dominant carrier signal;
a plurality of successive output means (106, 116, 16), each said successive output means (106, 116, 16) having a first input coupled to an immediately preceding phase lock loop means and an output port coupled to a next successive phase lock means, each said output means for producing an output signal having said next successive dominant carrier signal suppressed;
a plurality of successive delay means (105, 115, 15), each of said successive delay means (105, 115, 15) coupled between said output port of an immediately preceding output means and a second input port of a next successive output means, said delay means (105, 115, 15) for receiving said output signal produced by the immediately preceding output means and producing a delayed signal identical to said output signal and being selectively delayed with respect to said output signal, said

delay signal coupled to said second input port of said next successive output means.

12. Apparatus as in one of the preceding Claims characterized in that said first replica signal is given by the relation:

$$s_1(t) = B_1\cos[(\omega_1 + \epsilon_X)t + \int_0^t m_K(a)da].$$

13. Apparatus as in one of the preceding Claims characterized in that said first signal as given by the relation:

$$m_1(t) = \int_0^t m_1(a)da.$$

14. Apparatus for power division multiplexing a plurality of modulated carrier signals, said apparatus characterized by:
a plurality of demodulator means (PLL_1, PLL_2, PLL_3, ..., PLL_N) for producing a plurality of signals representing the demodulated message of the most dominant carrier signal received by each of said plurality of demodulator means (PLL_1, PLL_2, PLL_3, ..., PLL_N) and for producing a plurality of replica signals representative of said most dominant carrier signals;
a plurality of output means (106, 116, 16);
a plurality of delay means (105, 115, 15) each having an input, each respectively coupled to an output of one of said output means (106, 116, 16) for producing first signals identical to signals received therefrom selectively delayed with respect to said received signals; and
each of said plurality of output means (106, 116, 16) being coupled to one of said demodulator means (PLL_1, PLL_2, PLL_3, ..., PLL_N) and to one of said delay means (106, 116, 16) for receiving and combining said first signals and said replica signals produced thereby and for producing a plurality of output signals, each of said output signals having the next successively dominant carrier signal of said input signal suppressed.

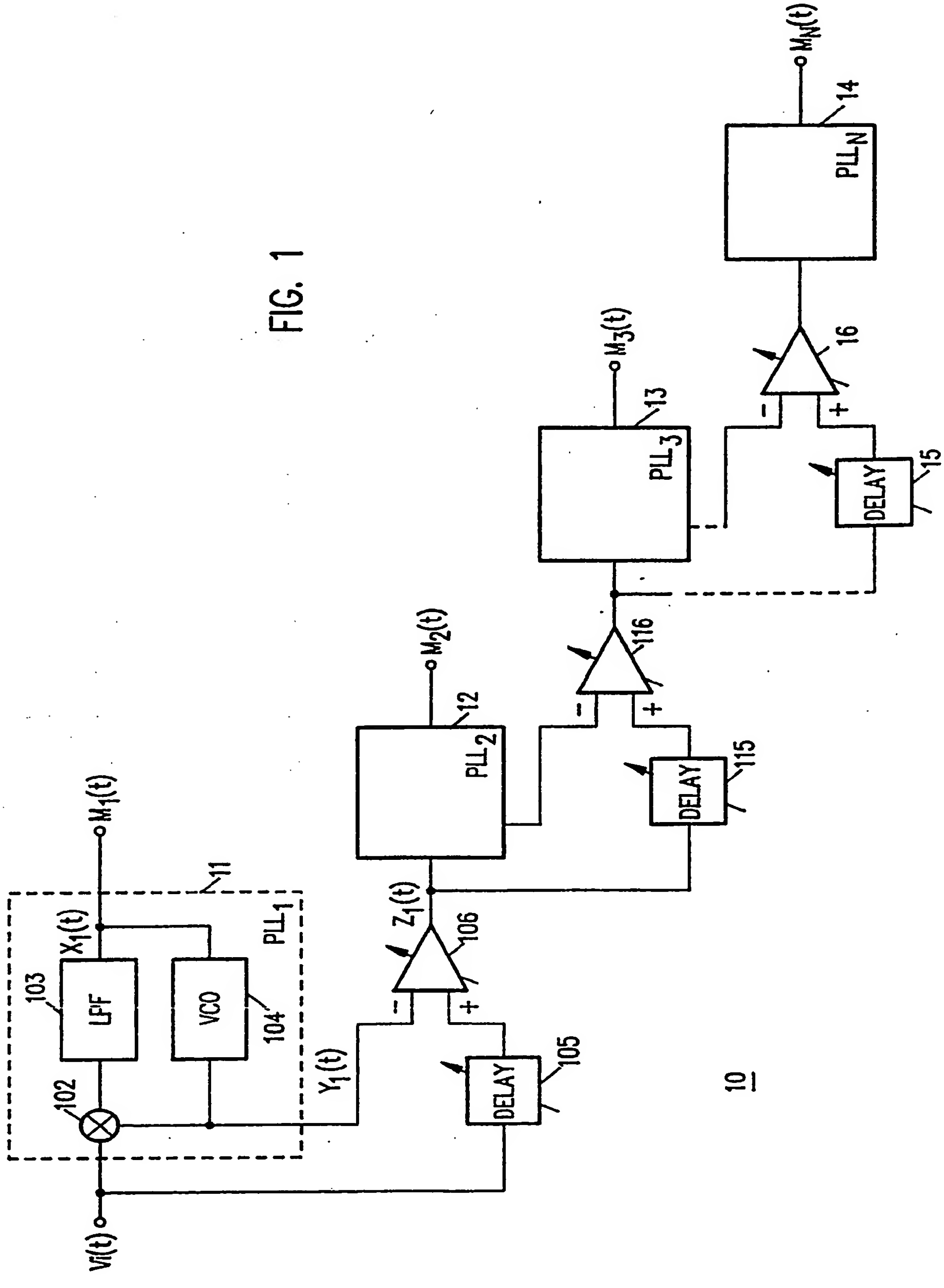
Vi(t)
102
103
LPF
X1(t)
VCO
104
PLL1
11
M1(t)
Y1(t)
DELAY
105
106
Z1(t)
PLL2
12
M2(t)
DELAY
115
116
PLL3
13
M3(t)
DELAY
15
16
PLLN
14
MN(t)
10

FIG. 1

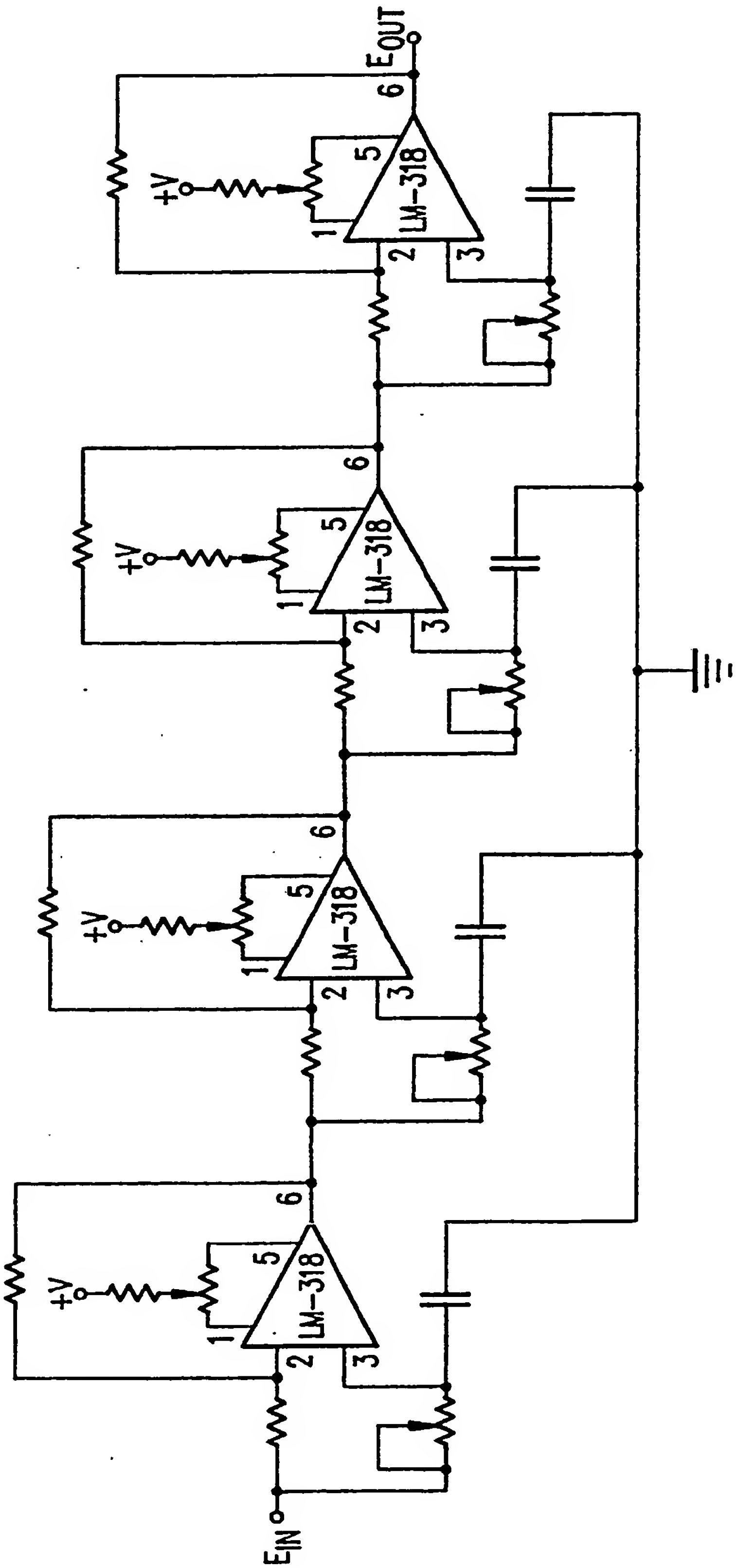

FIG. 2

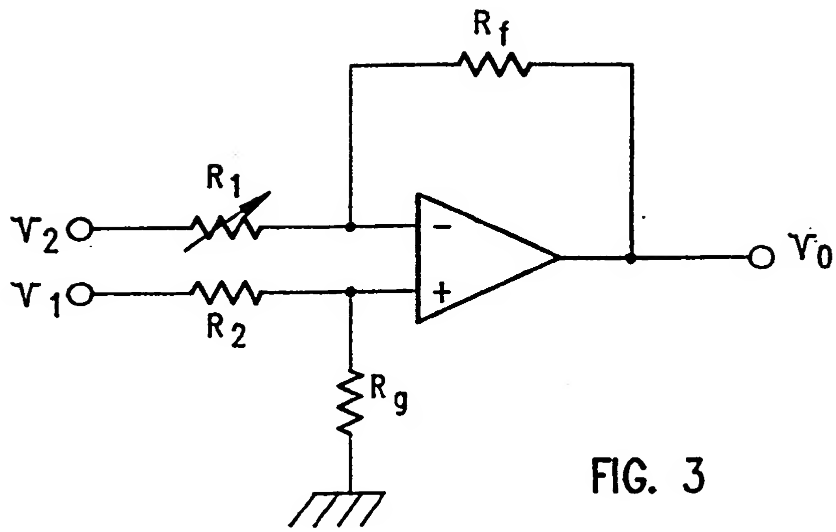
R f
R 1
V 2
V 1
R 2
R g
V 0
−
+

FIG. 3

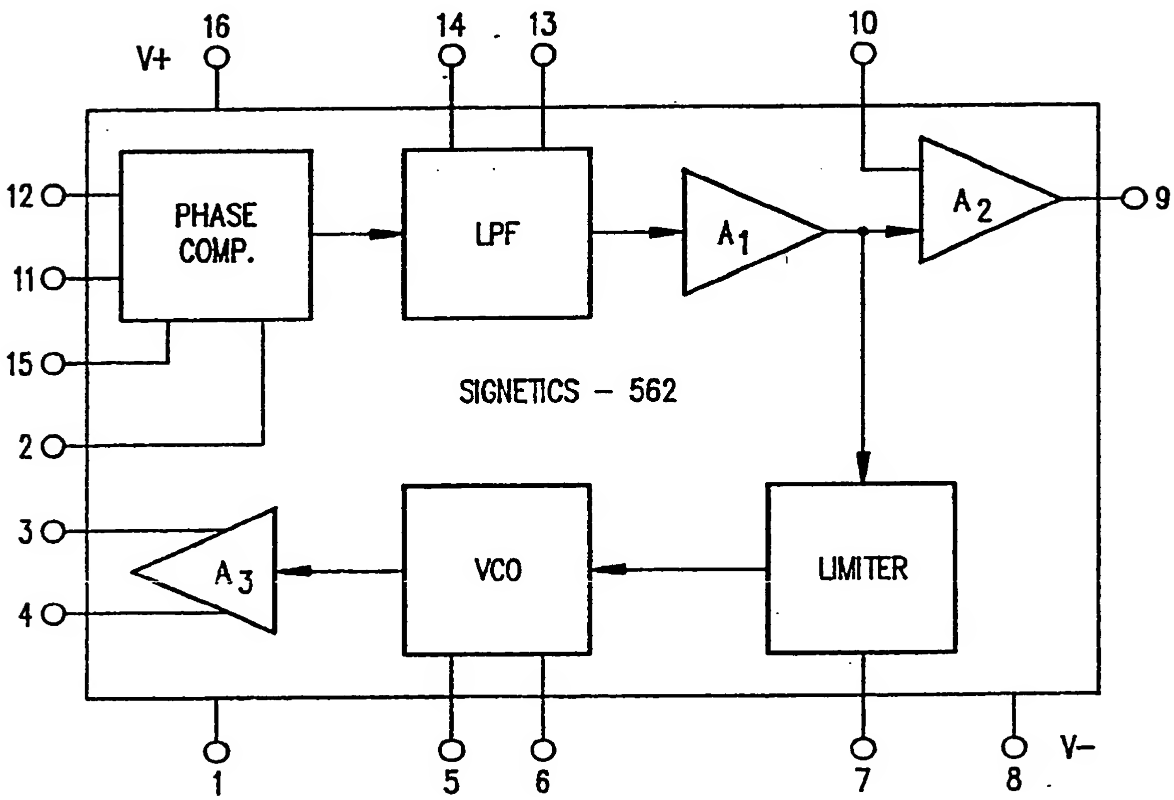
16
14
13
10
V+
12
11
15
2
3
4
9
PHASE COMP.
LPF
A 1
A 2
SIGNETICS − 562
A 3
VCO
LIMITER
1
5
6
7
8
V−

FIG. 4

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(54) Multiple use of an FM band.

(57) A signal receiving system (10) for receiving messages from each of several unequal amplitude FM carriers ($v_i(t)$) occupying the same portion of the frequency band. The capture effect associated with conventional frequency demodulators is utilized in a series of successively coupled phase lock loops (PLL_1, PLL_2, PLL_3, ..., PLL_N) to provide demodulation of all of several FM carrier signals including weaker carrier signals in the presence of dominant carrier signals. A phase lock loop demodulator (PLL_1) provides a demodulated signal representing the information contained in the most dominant carrier signal input to the phase lock loop (PLL_1). The phase lock loop (PLL_1 also provides a signal ($Y_i(t)$) which is a replica of the most dominant carrier signal in the input. The input signal ($V_i(t)$) is also delayed in a delay circuit (105) and input into an input port of an output circuit (106). The replica signal ($Y_i(t)$) is also coupled to an input port of the output circuit (106). The output circuit (106) produces an output signal ($Z_i(t)$) which is identical to the input signal ($V_i(t)$) except that the most dominant carrier signal is suppressed. The output signal ($Z_i(t)$) is then coupled to a successive phase lock loop (PLL_2) and delay circuit (115).

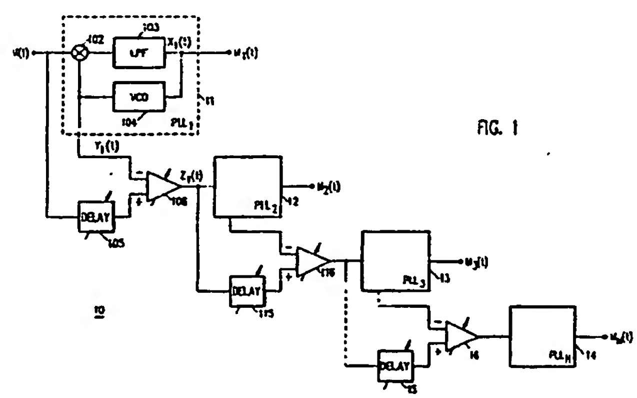

FIG. 1

EP 0 356 096 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 89 30 8225

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	US-A-3 873 931 (BASSE et al.) * Figure; abstract; column 1, line 53 - column 2, line 5; column 2, lines 14-17,36-58; column 3, lines 51-53; column 4, lines 3-5 *	1-14	H 03 D 3/24
A	US-A-4 027 264 (GUTLEBER) * Figure 2; column 1, lines 33-54; column 2, lines 22-29,43-51; column 3, lines 15-21; column 4, lines 1-10 *	1-8	
X	IEEE TRANSACTIONS ON COMMUNICATIONS, vol. COM-25, no. 12, December 1977, pages 1480-1485; T.S. SUNDRESH et al.: "Maximum A posteriori estimator for suppression of interchannel interference in FM receivers" * Figure 7; page 1483, right-hand column, last paragraph *	1-14	
A	US-A-3 733 565 (PIERRET) * Figures 1,2; abstract *	9	**TECHNICAL FIELDS SEARCHED (Int. Cl.5)**
A	P. HOROWITZ et al.: "The art of electonics", 2nd edition, pages 175-251, Cambridge University Press, Cambridge, GB; chapter 4: "Feedback and operational amplifiers" * Page 184, last paragraph; figures 4-18 *	10	H 03 D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	16-08-1990	GOULDING C.A.

CATEGORY OF CITED DOCUMENTS

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